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Combating nuclear smuggling? Exploring drivers and challenges to detecting nuclear and radiological materials at maritime facilities

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ABSTRACT
International concern over nuclear terrorism has grown during the past few decades. This has driven a broad spectrum of efforts to strengthen nuclear security globally, including the widespread adoption of radiation-detection technology for border monitoring. Detection systems are now deployed at strategic locations for the purported purpose of detecting and deterring the smuggling of nuclear and radioactive materials. However, despite considerable investment in this area, few studies have examined how these programs are implemented or the operational challenges they face on a day-to-day basis. This article seeks to address this with a focus on radiation-detection efforts at maritime facilities. Utilizing practitioner interviews and a survey, this article identifies the factors that influence the planning and use of these systems in this fast-moving environment. The results clearly demonstrate that the implementation of these systems varies significantly across different national and organizational contexts, resulting in a fragmented global nuclear-detection architecture, which arguably undermines efforts to detect trafficked nuclear-threat materials. Greater consideration should therefore be given to developing international standards and guidance, designing and adopting tools to support key parts of the alarm assessment process, and broader sharing of good practice.

KEYWORDS
nuclear terrorism; nuclear security; radiation detection; maritime supply chain; border monitoring

The theft and accidental loss of nuclear and radioactive materials, resulting in so-called material out of regulatory control (MORC), is a global issue of long-standing concern. A number of sources document this persistent phenomena, most notably the International Atomic Energy Agency (IAEA) Incident Trafficking Data Base (ITDB), established in 1995.[1] The ITDB contains information on several thousand "unauthorized activities" involving a wide range of materials including radiological sources, radioactively contaminated scrap metal, natural and highly enriched uranium, and plutonium,[2] the loss of

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[1] ITDB, IAEA, <www-ns.iaea.org/security/itdb.asp>.
[2] "IAEA Incident and Trafficking Database: Incidents of Nuclear and Other Radioactive Material out of Regulatory Control—2017 Fact Sheet," IAEA, December 31, 2016, <www.iaea.org/sites/default/files/17/12/itdb-factsheet-2017.pdf>, p. 3.

control over which represents a clear health risk and environmental hazard.[3] The ITDB also contains several hundred incidents that involve the deliberate trafficking or malicious use of certain nuclear and radioactive materials.[4] Studies have illustrated how, if obtained in sufficient quantities by actors such as terrorist groups, these materials could cause significant death, destruction, and disruption.[5]

International efforts to reduce the loss of material control and aid their recovery date back several decades. These include improving physical protection measures at facilities holding nuclear and radiological materials, replacing high-risk materials with safer alternatives, and sting operations designed to flush materials out of black-market circulation.[6] One nuclear-security measure that has garnered extensive investment in recent years is the installation of border-monitoring systems, focused on identifying the characteristic radiation emitted by nuclear and radiological materials. Billions of dollars have been spent on deploying detection technology at national border crossings, key chokepoints, and high-value targets around the world.[7] These systems can reduce nuclear and radiological risks in two interrelated ways. First, direct detection can disrupt attempts to illicitly traffic materials while in motion. Second, raising technical barriers to covertly moving materials serves to dissuade adversaries from engaging in illicit trafficking, a commonly utilized counterterrorism strategy of deterrence-by-denial.[8]

Given the scale of efforts to develop and deploy border-monitoring systems, it is surprising that few studies have sought to explore how these systems are implemented, the challenges encountered in their operation, and the opportunities available to further strengthen the global nuclear-detection architecture. Most research in this area has either examined high-level policy decisions, explored hypothetical scenarios involving the trafficking of materials, or focused on narrow technical issues. Official reports have tended to assess the effectiveness of particular programs by focusing on issues such as the number of systems installed, equipment uptime, and the provision of training.[9]

One explanation for the lack of detailed published studies in this domain is the risk of publicly revealing sensitive operating information, which adversaries could potentially exploit to circumvent detection systems. This is a legitimate concern when studying the implementation of this and indeed any nuclear-security measure. However, it is possible

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[3] See, for instance, J.A. Azuara, "Main issues in the Acerinox Event," in IAEA, *Safety of Radiation Sources and Security of Radioactive Materials*, Proceedings of an international Conference, Dijon, France, September 14–18, 1998, pp. 45–51; IAEA, *The Radiological Accident in Lilo* (Vienna, 2000).

[4] "IAEA Incident and Trafficking Database," p. 2.

[5] There is wide variation in terms of impact across the different weapon types and scenarios in which radiological and nuclear materials could be used. For a detailed discussion, see Charles D. Ferguson and William C. Potter, *The Four Faces of Nuclear Terrorism* (London: Routledge, 2005).

[6] "Measures to Improve the Security of Nuclear Materials and Other Radioactive Materials," IAEA Board of Governors General Conference, GOV/2001/37-GC(45)/20, August 14, 2001; Miles A. Pomper, Ferenc Dalnoki-Veress, and George M. Moore, "Treatment, Not Terror: Strategies to Enhance External Beam Cancer Therapy in Developing Countries while Permanently Reducing the Risk of Radiological Terrorism," Stanley Foundation, February 2016, <www.stanleyfoundation.org/publications/report/TreatmentNotTerror212.pdf>; Emily S. Ewell, "NIS Nuclear Smuggling since 1995: A Lull in Significant Cases?" *Nonproliferation Review*, Vol. 5 (1998), pp. 120–23.

[7] Tyson Gustafson, "Radiological and Nuclear Detection Devices," Nuclear Threat Initiative, April 19, 2017, <www.nti.org/analysis/articles/radiological-nuclear-detection-devices>.

[8] Jeffrey W. Knopf, "Wrestling with Deterrence: Bush Administration Strategy after 9/11," *Contemporary Security Policy*, Vol. 29, No. 2 (2008), p. 241

[9] See, for example, US Government Accountability Office (GAO), "Combatting Nuclear Smuggling: NNSA's Detection and Deterrence Program Is Addressing Challenges but Should Improve Its Program Plan," GAO-16-460, June 2016, pp. 9–10, 21–22; Oak Ridge National Laboratory, "Nuclear Smuggling Detection and Deterrence FY2016: Data Analysis Annual Report," January 2017, pp. 13–14.

to mitigate this risk by purposefully limiting the specificity of the research conducted and information released. The following article takes this approach, with an anonymous survey used to probe the operation of radiation-detection systems at maritime facilities. Survey responses were contextualized using data from the existing literature and through a number of semi-structured interviews with academics and representatives of international organizations, shipping companies, regulators, and trade associations.[10] Information presented in this article is used to compare and contrast different border-monitoring systems, with care taken to ensure that specific countries and maritime facilities cannot be identified. For more details on the survey that underpins this study, please refer to the Appendix at the end of this article.

There are a range of different locations where radiation-detection systems are deployed, including airports, vehicle border-crossing points, subway systems, and government buildings. This study focuses on their use in the maritime supply chain, specifically with regard to the scanning of shipping containers at maritime facilities as opposed to other types of cargo. This is a key environment in which to combat the illicit trafficking of nuclear and radioactive materials, given the volume of global trade that is shipped by sea, with studies postulating that a "functional nuclear weapon" could be readily "moved about in an ordinary shipping container."[11]

To provide context for this study, this article starts by discussing how threat perceptions have shaped international efforts to detect radiation at maritime borders. This is followed by a general discussion on how these efforts can be deployed at maritime facilities and standard protocols governing their use. Next, the article explores how and why systems have been implemented at different facilities, the drivers behind their operation, and some of the difficulties encountered by those operating such systems, commonly referred to as "front-line officers" (FLOs). The closing discussion articulates a series of policy measures for improving the effectiveness of the global nuclear-detection architecture.

The global nuclear-detection architecture: evolving threat perceptions and response

The smuggling of nuclear materials across borders has been a persistent concern since the start of the atomic age, with efforts to identify and intercept materials evolving in response to the changing international geopolitical environment.

Early state-level concerns: the Cold War

In the United States, concerns were initially framed in terms of a clandestine Soviet attack, where a nuclear weapon might be delivered covertly by a means other than a missile or aircraft. In a closed Senate hearing in 1946, Robert Oppenheimer, director of the Manhattan Project, was asked about the possibility of Soviet operatives smuggling an atomic bomb into New York City. In response, Oppenheimer replied, "of course it could be done, and

[10] These interviews are drawn upon in this article in a non-attributable manner.
[11] Richard T. Kouzes, "Detecting Illicit Nuclear Materials: The Installation of Radiological Monitoring Equipment in the United States and Overseas Is Helping Thwart Nuclear Terrorism," *American Scientist*, Vol. 93, No. 5 (2005), p. 425.

people could destroy New York."[12] Discussion then turned to how such a device could be detected in transit, Oppenheimer famously exclaiming, "with a screwdriver" necessary to open and inspect every box or container entering the city.

The US Atomic Energy Commission later sanctioned a study into how highly enriched uranium (HEU) or plutonium, which forms the fissile core of a nuclear weapon, might be detected if smuggled into the United States.[13] The output, which became known as the "Screwdriver Report," was published in the 1950s and remains classified. It explored how both passive radiation and induced emissions could potentially be used to detect nuclear materials inside a container.[14] The report concluded that detection would only be successful at a relatively short range, and that passive radiation systems would be vulnerable to shielding.[15] The 1950s also saw the first practical deployment of radiation detectors for the purposes of border monitoring, with systems installed at a number of US air- and seaports.[16]

As other US adversaries developed nuclear weapons, concerns regarding potential clandestine nuclear attacks broadened. The 1970 US National Intelligence Estimate noted that China, lacking conventional means of delivery to attack or deter the United States with nuclear weapons, might "see some advantages in clandestinely introducing and emplacing nuclear weapons into the US."[17] There were also fears that, during heightened tensions between the United States and the Soviet Union, Beijing might smuggle into the United States a "nuclear device constructed as to appear to be of Soviet origin."[18] The report envisioned that such an incident could initiate a crisis between the two superpowers, serving Chinese interests.

There were also early concerns regarding the possible theft and smuggling of nuclear materials by non-state actors, more than 100 extortion threats (the majority of which were hoaxes) involving nuclear and radiological materials and weapons being reported from the early 1970s to the early 1990s.[19] In response, the United States established the Nuclear Emergency Search Team in the mid-1970s.[20] This team was tasked with countering nuclear and radiological threats by detecting and recovering nuclear and radiological materials, deactivating weapons, and helping to identify perpetrators.

Emergence of a new threat: the 1990s

In the 1990s, the perceived threat of nuclear and radiological terrorism increased as a result of several factors. First, some analysts believed that the end of the Cold War

12 Kay Bird, "The First Line against Terrorism," *Washington Post*, December 12, 2001, <www.washingtonpost.com/archive/opinions/2001/12/12/the-first-line-against-terrorism/4a53ee41-f528-4a4f-9f9b-64d38353a03c/?utm_term=.ae16fd1a0f95>.

13 Jerome I. Friedman and William A. Little, "Robert Hofstadter," *Biographical Memoirs*, Vol. 79, <www.nap.edu/read/10169/chapter/11#175>, p.175.

14 Wolfgang K.H. Panofsky, "Radiation Detectors," *New Yorker*, April 9, 2007, <www.newyorker.com/magazine/2007/04/09/mail>.

15 Ibid.

16 Jeffrey T. Richelson, *Defusing Armageddon: Inside Nest, America's Secret Nuclear Bomb Squad* (New York: W.W. Norton, 2009), p. 1.

17 Central Intelligence Agency, "The Clandestine Introduction of Nuclear Weapons into the US," TS 190512, July 1970, <www.cia.gov/library/readingroom/docs/DOC_0001211144.pdf> p. 4.

18 Ibid., pp. 4–5.

19 Richelson, *Defusing Armageddon*, pp. 236–40.

20 Cameron Reed, "The Nuclear Emergency Support Team (NEST)," *Physics and Society*, Vol. 42, No. 1 (2013), <www.aps.org/units/fps/newsletters/201301/reed.cfm>.

weakened political constraints on terrorist actions, ushering in an era of "new terrorism."[21] Attacks such as the 1993 World Trade Center bombing, Aum Shinrikyo's 1995 sarin attack on the Tokyo subway, and the 2000 bombing of the USS *Cole* in Yemen provided the evidentiary basis for a shift toward increasingly high casualties and, in the Aum Shinrikyo case, unconventional terrorism. Second, the collapse of the Soviet Union increased concerns over the availability of nuclear and radiological materials. Early reports offered lurid accounts of "loose nukes" leaking from the poorly secured arsenals of the former Soviet Union states (FSU).[22] While many allegations were quickly discounted, there remained a body of evidence showcasing disconcertingly common losses of weapon-useable nuclear materials.[23] Simultaneously, nuclear and radiological materials as well as contaminated consumer goods and scrap metal entered Central and Eastern Europe with increasing frequency, smuggled by criminals and other individuals.[24]

Starting in 1990, in response to the crossborder flows of radioactive materials, a number of European countries established radiation-detection systems at key border crossings, including seaports.[25] However, trafficking continued. In 1994, there were four notable interdictions in Germany involving the smuggling of HEU and plutonium.[26] In response, Germany sponsored a resolution at the 1994 IAEA General Conference, aimed at tackling the illicit trafficking of nuclear materials and improving the current disjointed efforts of states and international organizations.[27] Specifically, it argued for joint efforts involving the European Union and others actors in supporting the "installation of radiation monitoring equipment for border control purposes."[28]

This resolution arguably heralded the beginning of concerted international efforts to counter the illicit trafficking of radiological and nuclear materials. One specific outcome was the initiation of the Illicit Trafficking Radiation Assessment Program (ITRAP) in 1997.[29] ITRAP assessed the ability of commercially available detection systems to identify commonly smuggled nuclear and radiological materials and radioactively contaminated goods.[30] The results of this work fed into an IAEA-sponsored guidance document that advised member states on the use of radiation detection at national borders.[31]

[21] Walter Laqueur, "Postmodern Terrorism: New Rules for an Old Game," *Foreign Affairs*, September/October 1996, <www.foreignaffairs.com/articles/1996-09-01/postmodern-terrorism-new-rules-old-game>.

[22] John H. Nuckolls, "Post-Cold War Nuclear Dangers: Proliferation and Terrorism,"Science, Vol. 267, No. 5201 (1995), pp. 1112–14.

[23] William C. Potter, "Before the Deluge? Assessing the Threat of Nuclear Leakage from the Post-Soviet States," *Arms Control Today*, Vol. 25, No. 8 (1995), pp. 9–16.

[24] Lyudmila Zaitseva and Friedrich Steinhäusler, "Nuclear Trafficking Issues in the Black Sea Region," Non-proliferation Papers No. 39, Stockholm International Peace Research Institute, April 2014, <www.sipri.org/publications/2014/eu-non-proliferation-papers/nuclear-trafficking-issues-black-sea-region>, p. 3.

[25] G. Smagala, "Measures to Detect and Control Radioactive Contaminated Metallurgical Scrap at Border Checkpoints in Poland," in *Workshop on Radioactive Contaminated Metallurgical Scrap* (New York and Geneva: United Nations Economic Commission for Europe), pp. 123–30; M. Fabretto, "Monitoring of Scrap Loads at Gorzia Border Checkpoints: A Thirty Months Experience and Some Suggestions," Ibid., pp. 31–42.

[26] GAO, "Report to the Ranking Minority Member, Subcommittee on Emerging Threats and Capabilities," GAO-02-426, <www.gao.gov/assets/240/234392.pdf#page=36>, p. 36

[27] IAEA General Conference, GC(38)/RES/15, "Measures against Illicit Trafficking in Nuclear Material," September 1994, <www-legacy.iaea.org/About/Policy/GC/GC38/GC38Resolutions/English/gc38res-15_en.pdf>.

[28] 38th IAEA General Conference, "Secondary Plenary Meeting," September 1994, <www.iaea.org/About/Policy/GC/GC38/GC38Records/English/gc38or-2_en.pdf>, p. 6.

[29] P. Beck, K. Duftschmid, and C. Schmitzer, "ITRAP: The Illicit Trafficking Radiation Assessment Program," in *Safety of Radiation Sources and Security of Radioactive Materials*, pp. 265–69.

[30] Ibid.

[31] Three technical guidance documents were produced: IAEA, "Prevention of the Inadvertent Movement and Illicit Trafficking of Radioactive Materials," IAEA-TECDOC-1311, September 2002, <www-pub.iaea.org/MTCD/Publications/

The resolution also served to reorient bilateral support programs to the FSU, from physical protection to illicit trafficking, the United States and other actors increasing efforts to provide radiation equipment and training for customs officers and other border-based agencies.[32]

Nevertheless, despite increased budgets and a higher profile, efforts to institute border-monitoring systems struggled from a lack of coordination. For example, US efforts to counter illicit trafficking through providing radiation-detection systems, training, and other assistance were split between a considerable number of federal agencies.[33] With no single agency in charge of leading US efforts, there was little alignment of approaches to border-security enhancement, resulting in varying capabilities of the detection equipment installed within different countries and facilities.[34] As a result, certain border crossings were "more vulnerable to nuclear smuggling than others."[35]

Toward a global system: the 2000s

While the perceived threat of nuclear terrorism increased during the 1990s, September 11, 2001 brought about a sea change in thinking. Analysts such as Brian Jenkins from the RAND Corporation saw a dramatic shift from terrorists wanting "a lot of people watching, not a lot of people dead … [to, increasingly,] terrorists want[ing] a lot of people watching and a lot of people dead."[36] Because nuclear materials could facilitate particularly devastating attacks, the international community found a renewed focus on nuclear security, which expanded and reorientated the illicit trafficking agenda.

Previously, relatively few programs targeted the international flow of goods or containerized trade specifically, and most nuclear-material interdictions resulted from police investigations. However, post-9/11, the growing internationalization of terrorism and related policy responses resulted in a heightened interest in border security.[37] A wider range of states now appeared vulnerable to attacks carried out with nuclear materials smuggled into their homeland. Changing priorities can be seen in budget allocations.

PDF/te_1311_web.pdf>; IAEA, "Detection of Radioactive Materials At Borders," IAEA-TECDOC-1312, September 2002, <www-pub.iaea.org/MTCD/Publications/PDF/te_1312_web.pdf>; IAEA, "Response to Events Involving the Inadvertent Movement or Illicit Trafficking of Radioactive Materials," IAEA-TECDOC-1313, September 2002, <www-pub.iaea.org/MTCD/Publications/PDF/te_1313_web.pdf>.

32 As just one example, funding provided to the US Export Control and Related Border Security Assistance program expanded from $3 million in fiscal year 1998 to $40.1 million in fiscal year 2001. GAO, "U.S. Efforts to Help Other Countries Combat Nuclear Smuggling Need Strengthened Coordination and Planning," GAO-02-426, <www.gao.gov/assets/240/234392.pdf>, p. 10

33 US agencies involved in counter-illicit smuggling efforts included the Department of Energy (DoE), Department of State (DoS), Department of Defence (DoD), the US Customs Service, the Federal Bureau of Investigation, and the US Coast Guard. Radiation-detection equipment was provided through the Office of the Second Line of Defence (SLD) program in the DoE, the Nonproliferation and Disarmament Fund (DoS), the Export Control and Related Border Security Assistance program in the DoS, the Georgia Border Security and Law Enforcement program in the DoS, and the Cooperative Threat Reduction Programme and International Counterproliferation program in the DoD. GAO, "Report to the Ranking Minority Member, Subcommittee on Emerging Threats and Capabilities," GAO-02-426, <www.gao.gov/assets/240/234392.pdf#page=5>, p. 6–8.

34 Ibid., p. 11.

35 Ibid.

36 Brian M. Jenkins, "The New Age of Terrorism," in Brian M. Jenkins, ed., *McGraw-Hill Homeland Security Handbook* (Santa Monica, CA: RAND, 2006).

37 UN Security Council Resolution (UNSCR) 1540, for example, placed a legal obligation on all UN member states to put in place "appropriate effective border controls" to prevent the trafficking of weapons-of-mass-destruction-(WMD)-related goods. United Nations, Security Council Resolution 1540, April 28, 2004, <www.un.org/ga/search/view_doc.asp?symbol=S/RES/1540%20(2004)>.

In the nine years from 1992 to 2001, the United States spent around $86 million on international counter-nuclear-smuggling efforts, whereas more than $700 million was appropriated in the four years from 2001 to 2005.[38]

Seaports emerged as a distinct focus in two ways. First, states sought to protect their own borders using radiation-detection systems. Both the United States and United Kingdom initiated radiation-detection programs at domestic seaports and other border crossings shortly after 9/11. Under Project Cyclamen, fixed radiation-detection systems were installed to scan incoming goods at three major UK ports and one international airport.[39] This has since evolved into Programme Cyclamen, which now covers most major UK port facilities, major airports, and rail links with mainland Europe.[40] A similar situation developed in the United States under the Department for Homeland Security, albeit on a commensurately larger scale.

Second, states deemed at high risk of illicit trafficking often lacked the capacity to develop and deploy radiation-detection systems, and were doubly vulnerable as a result. Although this was recognized in the 1990s, 9/11 reinvigorated existing support programs and led to new initiatives by international organizations and third-party states. For benefactors, overseas detection capabilities acted as a second line of defense in the event that the first line of defense—physical protection at nuclear facilities in beneficiary states—was breached.[41]

New programs dedicated to maritime supply-chain security were initiated at this time, including the National Nuclear Security Administration (NNSA) Megaports Initiative.[42] This focused on enabling the screening of containerized freight for radiological and weapon-useable nuclear materials at non-US ports. Detection systems were installed at facilities in tens of countries. Host-country officials operated and maintained the deployed systems, with US support provided to each Megaports installation for three years. The priority accorded to container scanning at foreign seaports is borne out by the program's $850 million budget from 2003 to 2011, with an additional $1 billion spent in fifty-nine partner countries from 2011 to 2015.[43]

The importance of combating illicit trafficking and strengthening detection systems continues to feature prominently in international fora. For instance, the Nuclear Security Summit (NSS) process addressed border monitoring in several summit communiqués. The 2016 NSS joint statement, endorsed by more than ten states, called for increased national, regional, and international coordination of efforts to detect and remove nuclear and radiological materials from the maritime supply chain.[44] This was

[38] GAO, "Report to the Ranking Minority Member, Subcommittee on Emerging Threats and Capabilities," GAO-02-426, May 2002, <www.gao.gov/assets/240/234392.pdf#page=5>, p. 2; GAO, "Combating Nuclear Smuggling: Efforts to Deploy Radiation Detection Equipment in the United States and in Other Countries," GAO-05-840T, June 21, 2005, <www.gao.gov/assets/120/111799.pdf>, p. 2.

[39] *The Telegraph*, "Ports Equipped to Deter Nuclear Attack," May 14, 2003, <www.telegraph.co.uk/news/1430029/Ports-equipped-to-deter-nuclear-attack.html>.

[40] UK Parliament, "Memorandum Submitted by the Home Office," Select Committee on Defence, <https://publications.parliament.uk/pa/cm200304/cmselect/cmdfence/417/417we02.htm>; David Blunkett, speech to the House of Commons, June 10, 2004, Parliamentary Debates, Commons, Vol. 422 (2004), Cols. 525–26.

[41] Richard T. Kouzes, "Detecting Illicit Nuclear Materials: The Installation of Radiological Monitoring Equipment in the United States and Overseas Is Helping Thwart Nuclear Terrorism," *American Scientist*, Vol. 93, No. 5 (2005), p. 442.

[42] GAO, "Combating Nuclear Smuggling: Megaports Initiative Faces Funding and Sustainability Challenges," GAO-13-37, October 2012, <www.gao.gov/assets/650/649759.pdf>.

[43] Ibid. p. 9; GAO, "Combating Nuclear Smuggling: NNSA's Detection and Deterrence Program Is Addressing Challenges but Should Improve Its Program Plan," GAO-16-460, June 2016, <www.gao.gov/assets/680/677895.pdf>, p. 8.

[44] "Joint Statement on Maritime Supply Chain Security," Nuclear Security Summit, April 5, 2016, <www.nss2016.org/document-center-docs/2016/4/1/joint-statement-on-maritime-supply-chain-security>.

supplemented by a “Best Practice Guide” outlining important practical considerations in establishing and sustaining such programs within the maritime domain.[45]

However, international approaches in this area frequently diverge, leading to tension and controversy. In 2007, clearly driven by national-security concerns, the Geoge W. Bush administration developed legislation requiring 100 percent of US-bound containers to be scanned by both radiation detection and nonintrusive imaging equipment in their port of origin.[46] This requirement was to have been implemented by 2012, but the deadline has been extended in two-year increments to the present day.[47] The European Union and others have been “fiercely opposed” to such a measure, arguing that it would disrupt trade, dramatically increase costs, and produce few security improvements.[48]

Detecting nuclear materials within the maritime supply chain: an overview

There are particular challenges to detecting smuggled nuclear and radiological material in the maritime environment. This is largely due to the volume and speed of trade flows; the international shipping industry conducts an estimated 90 percent of global trade.[49] This share has grown considerably over recent decades, driven by a widespread move to containerization in the 1980s to 2000s. Recent estimates put the number of 20- or 40-foot containers in circulation at over 43 million.[50] At a busy international port, such as Rotterdam in the Netherlands, more than ten million 20-foot equivalent units (TEUs) pass through port facilities each year, processing tens of thousands of containers every day.[51] This includes the import and export of containers and their transshipment—where containers are offloaded from one ship before being loaded onto another, typically without leaving a designated customs area. Ports will also handle non-containerized cargo and may have specific terminals dedicated to the handling of dry bulk (such as coal or grain), liquid bulk (such as industrial chemical or petroleum), breakbulk (such as pipes or machinery), and liquified natural gas.[52]

The maritime supply chain therefore represents a huge and growing cargo stream within which to identify radioactive and nuclear contraband, a particularly acute challenge considering as little as a few kilograms of certain materials could pose a significant

45 “Nuclear Security Summit Enhancing the Security of the Maritime Supply Chain Gift Basket: Best Practice Guide for Removing Nuclear and Radiological Materials that Are out of Regulatory Control from the Global Maritime Supply Chain,” Nuclear Security Summit, March 2016, <https://static1.squarespace.com/static/568be36505f8e2af8023adf7/t/57051237859fd04c9fdd0699/1459950136051/Joint±Statement±on±Maritime±Supply±Chain±Security±Best±Practices.pdf>.

46 The Act noted that “A container that was loaded on a vessel in a foreign port shall not enter the United States (either directly or via a foreign port) unless the container was scanned by nonintrusive imaging equipment and radiation detection equipment at a foreign port before it was loaded on a vessel.” See “Implementing Recommendations of the 9/11 Commission Act of 2007,” Public Law 110–53, 110th Congress, August 3, 2007.

47 A two-year extension was passed in 2012, 2014, 2016, and seemingly 2018. See section 1701 (b) (4) of the Act.

48 Dimitrios Anagnostakis, “Securing the Transatlantic Maritime Supply Chains from Counterterrorism: EU–U.S. Cooperation and the Emergence of a Transatlantic Customs Security Regime,” *Studies in Conflict & Terrorism*, Vol. 39, No. 5 (2016), p. 463.

49 “Shipping and World Trade—Overview,” International Chamber of Shipping, <www.ics-shipping.org/shipping-facts/shipping-and-world-trade>.

50 “How Many Shipping Containers Are There in the World?” Budget Shipping Containers, <www.budgetshippingcontainers.co.uk/info/how-many-shipping-containers-are-there-in-the-world/>.

51 “Top 50 World Container Ports,” World Shipping Council, <www.worldshipping.org/about-the-industry/global-trade/top-50-world-container-ports>.

52 John Frittelli and Jennifer E. Lake, “Terminal Operators and Their Role in U.S. Port and Maritime Security,” CRS Report for Congress, January 19, 2007, p. 2.

threat.[53] Identification must occur rapidly in order to avoid significant disruption to the flow of legitimate goods. Radioactive and nuclear materials are also not the only contraband passing through the maritime supply chain. Far more commonly shipped items include narcotics, conventional weapons, and explosives.[54] Consequently, striking the balance between monitoring for nuclear and radiological materials and other illegal imports is a perennial difficulty given resource constraints including, not least, the availability of FLOs.[55]

Given the challenges outlined above and the limited time and resources available, risk-management-based approaches are typically used to focus inspection efforts aiming to detect contraband passing through maritime facilities.[56] Often this includes the use of profiling tools to identify high-risk containers, for example, the Automated Targeting System (ATS) deployed by the US Department of Homeland Security.[57] This and other systems utilize a set of risk indicators based on recent intelligence and past incidences. Cargo is evaluated against these indicators drawing on information from the customs manifest, shipments that score above a certain pre-defined threshold selected for further inspection.

However, these types of risk-based approaches may not provide the same level of insight when it comes to nuclear and radiological materials.[58] A relative dearth of incidences makes it difficult to determine trends in nuclear and radiological materials trafficking. Furthermore, studies have suggested that smugglers are likely to take a different approach to smuggling nuclear and radiological materials;[59] for contraband that is frequently shipped, such as narcotics, the interception of a certain percentage may be seen as an acceptable loss.

Given the difficulties in using profiling tools to flag suspected shipments of nuclear and radiological materials, the emphasis has been on detection systems that scan a significant fraction of container cargo flows for physical signatures characteristic of nuclear and radiological materials. These typically include passive detectors that measure gamma or neutron emissions resulting from the radioactive decay of threat materials.[60] Active detectors are also employed; for instance, X-ray radiography can create an internal image of containers, identifying potential shielding materials that might be used by smugglers to suppress radioactive emissions. Detectors vary in terms of sensitivity, cost, robustness,

[53] In this context, materials of particular concern (threat materials) include fissile materials such as plutonium and HEU and strong radioactive sources (IAEA Category 1, 2, and 3). For a discussion on the destructive and disruptive potential of different nuclear and radiological materials please see Charles D. Ferguson and William C. Potter, *The Four Faces of Nuclear Terrorism* (New York: Routledge, 2005).

[54] Hugh Griffiths and Michael Jenks, "Maritime Transport and Destabilizing Commodity Flows," SIPRI Policy Paper 32, 2012, <www.sipri.org/sites/default/files/files/PP/SIPRIPP32.pdf>, p. 1.

[55] This delicate balance occasionally manifests in the public domain; see Daniel Boffey, "'Dirty Bombs' May Have Been Missed by Private Border Staff as Games Approach," *The Guardian*, July 7, 2012 <www.theguardian.com/uk/2012/jul/07/border-agency-terrorism-games-dirty-bombs>.

[56] "Revised KYOTO Convention," World Customs Organization, 2006, <www.wcoomd.org/en/topics/facilitation/instrument-and-tools/conventions/pf_revised_kyoto_conv.aspx>.

[57] GAO, "Supply Chain Security: CBP Needs to Conduct Regular Assessments of Its Cargo Targeting System," October 2012, <www.gao.gov/assets/650/649695.pdf>.

[58] Ibid.

[59] Gary M. Gaukler, Chenhua Li, Yu Ding, and Sunil S. Chirayath, "Detecting Nuclear Materials Smuggling: Performance Evaluation of Container Inspection Policies," *Risk Analysis*, November 1, 2011, pp. 535–46.

[60] Jonathan Medalia, "Detection of Nuclear Weapons and Materials: Science, Technologies, Observations," Congressional Research Service, June 4, 2010, <https://fas.org/sgp/crs/nuke/R40154.pdf>.

portability, and their ability to distinguish between different types of nuclear and radiological material, and therefore are most effective when employed in combination.[61]

To operate efficiently, detection systems must be able to distinguish illicit nuclear and radiological materials from common commodities shipped through the maritime supply chain which can also produce significant radioactive emissions. These include radioactive isotopes with legitimate medical and industrial uses, as well as naturally occurring radioactive material (NORM), including granite, bananas, and cat litter.[62] This is far from a trivial task, given that an adversary may seek to mask the radioactive signature of undeclared nuclear or radioactive material by including it, for example, within a NORM shipment. Systems also have to handle a host of ever-changing local factors, including varying background radiation levels, different container speeds, and cross-talk from other lanes.[63]

Detection protocols: scanning, alarms, and response

Typically, maritime facilities employ a multistage detection protocol. In the first stage, containers move through a passive detector, usually a fixed radiation portal monitor (RPM).[64] On average, a complete scan of a single container takes under a minute, causing only minor disruption to the flow of cargo.[65] At most maritime facilities, this initial scan involves measuring the gamma (and if available neutron) radiation as the container passes through the RPM.[66] If neutrons are detected or if the total gamma radiation received exceeds a predetermined threshold, it triggers an alarm. For imports and exports, a scan typically occurs when a container passes through a point of entry or exit to the port, while for transshipments it will take place between unloading and reloading. If there is no alarm, the container continues on its way. If an alarm is raised, officials investigate further. Here, there are three possibilities: a false alarm, an innocent alarm, or a non-innocent alarm.[67]

A false alarm can occur when no radioactive material is present and may be caused by an equipment malfunction or a temporary fluctuation in local radiation levels. Innocent alarms are triggered by the legitimate shipment of NORM or radioactive sources used for industrial, medical, or other purposes. Non-innocent alarms are caused by radioactive material outside of regulatory control, including orphan sources or trafficked nuclear materials. FLOs assess the alarms by analyzing both the total radiation reading and the profile of a container.[68] This is compared against the declared content of the container in the shipment manifest, which should list any hazardous or radioactive

[61] Ibid., p. 105.
[62] World Nuclear Association, "Naturally-Occurring Radioactive Materials (NORM)," December 2016, <www.world-nuclear.org/information-library/safety-and-security/radiation-and-health/naturally-occurring-radioactive-materials-norm.aspx>.
[63] For examples of differences in background radiation levels, see "Nuclear Smuggling Detection and Deterrence FY2016: Data Analysis Annual Report," Oak Ridge National Laboratory, January 2017, pp.13–14; Tom Burr, James R. Gattiker, Kary Myers, and George Tompkins, "Alarm Criteria in Radiation Portal Monitoring," *Applied Radiation and Isotopes*, No. 65 (2007), p. 580.
[64] La Fonda Sutton-Burke, "Detection Instruments: Operation and Maintenance Challenges," Technical Meeting on Radiation Detection Instruments for Nuclear Security," IAEA, Division of Nuclear Security, Vienna, April 4, 2016.
[65] Gary M. Gaukler, Chenhua Li, Yu Ding, and Sunil S. Chirayath, "Detecting Nuclear Materials Smuggling: Performance Evaluation of Container Inspection Policies," *Risk Analysis*, November 1, 2011, p. 534.
[66] Radiation-detection expert at international organization, personal interview with one of the authors, July 12, 2018.
[67] IAEA, "Nuclear Security Systems and Measures for the Detection of Nuclear and Other Radioactive Material out of Regulatory Control," IAEA Nuclear Security Series No. 21, 2013, p. 37
[68] Radiation readings are taken at fractions of a second as the container passes through the RPM. These can be used to construct a radiation profile of counts versus container occupancy time.

materials.[69] FLOs look for anomalies that might indicate the presence of undeclared materials, such as a sharp spike in the radiation profile, which could indicate the presence of an undeclared radioactive source within a shipment of NORM.[70]

If it is not possible to adequately determine the cause of the alarm, a secondary inspection is conducted on the container. Typically, a container is moved out of the traffic flow to a secure area, before a manual external inspection is undertaken using a passive, handheld radioisotope identification device (RIID).[71] RIIDs can distinguish between specific radioisotopes so that a comparison can be made with each commodity listed on the shipment manifest. While the time taken to conduct a secondary inspection will vary, studies estimate that manual container scanning takes one customs officer approximately twenty minutes to complete.[72] X-rays may also be taken of the cargo as part of a secondary inspection. Spectroscopic portal monitors can both detect radiation and identify the radioactive source, which could in theory replace RPMs and eliminate the need for secondary inspections, though these have struggled in field testing and have yet to be widely deployed.[73]

In cases where secondary inspections are inconclusive, a further, tertiary inspection may be performed. This would typically be undertaken by certified radiation experts and may involve the unpacking of the container contents to determine the source of the radiation readings. So-called "manual unstuffing" is a far more labor-intensive process; one study estimates the costs of five inspectors manually inspecting one 40-foot container over for three hours.[74]

Radiation detection in practice: implementation, drivers, and challenges

As outlined previously, this study makes use of survey data and interviews conducted with practitioners involved in the planning, operation, and regulation of radiation-detection systems at maritime facilities around the world.[75] This information is combined with the existing literature and used to explore how and why radiation-detection systems are implemented for border monitoring at maritime facilities. This section begins by examining the deployment and operation of border-monitoring systems of different facilities. This is followed by a discussion of the various national and commercial drivers that influence the setup and operation of such systems. Finally, the section explores some of the practical challenges encountered by FLOs.

Implementation: how is radiation-detection capability deployed and used?

IAEA guidance recommends developing a national strategy for identifying and recovering nuclear and radiological MORC when establishing radiation-detection

69 "International Maritime Dangerous Goods (IMDG) Code, 2016 Edition," International Maritime Organization, <www.imo.org/en/Publications/Documents/IMDG%20Code/IMDG%20Code%202016%20Edition/QK200E_122017.pdf>.
70 Radiation-detection expert at international organization, personal interview with one of the authors, July 12, 2018.
71 "Evaluating Testing, Costs, and Benefits of Advanced Spectroscopic Portals for Screening Cargo at Ports of Entry Interim Report (Abbreviated Version)," National Academy of Sciences, 2009, p. 3.
72 Nitin Bakshi, Stephen E. Flynn, and Noah Gans, "Estimating the Operational Impact of Container Inspections at International Ports," *Management Science*, Vol. 57, No. 1 (2011), p. 10.
73 GAO, "Combating Nuclear Smuggling: Lessons Learned from Cancelled Radiation Portal Monitor Program Could Help Future Acquisitions," GAO-13-256, May 2013, pp. 10–11.
74 Stephen E. Flynn, "America the Vulnerable," *Foreign Affairs*, Vol. 81, No. 1 (2002), <www.foreignaffairs.com/articles/2002-01-01/america-vulnerable>.
75 For more details on the survey that underpins this study, please refer to the Appendix at the end of this article.

architecture.[76] This should be implemented within an appropriate legal and regulatory framework, drawing on the support of competent authorities and specialized technical agencies, to help translate high-level political goals into effective operational practice. The majority of this study's survey respondents identified the utility of national guidelines and processes governing the development and use of radiation-detection systems.[77] According to one respondent, "National labs provide guidance on needs. Another government agency … then evaluates[s] and purchases the equipment according to [these] recommendations … . The Government Accountability Office ensures purchased equipment is … used and installed effectively."[78] However, a smaller but nonetheless significant number of respondents indicated either that they did not have access to national-level guidance or processes relating to radiation detection, or were unsure whether these existed.[79]

There was significant variation in the percentage of total cargo that passed through radiation-detection systems. Approximately half of respondents reported over 80 percent of imported cargo underwent some form of radiation scanning, while roughly one-third put this figure at less than 20 percent.[80] The vast majority of maritime facilities that scanned under 20 percent also handled relatively small volumes of cargo—less than 500,000 TEU annually. The apparent inverse correlation between cargo volume and scanning percentage may simply reflect that efforts, including the US Megaports Initiative, have tended to prioritize the installation of detection systems at the busiest global ports.[81] However, high scanning rates at large ports do not necessarily provide protection against an intelligent adversary looking to smuggle radiological or nuclear material. Such an actor could purposefully choose a shipping route that bypasses large maritime facilities in an effort to minimize the chance of detection. This approach would be similar to criminal groups exercising jurisdictional arbitrage by "exploit[ing] the differences in national laws and regulations" to undertake their activities, i.e., moving operations or routing flows of goods through more favorable environments.[82]

The vast majority of cargo-scanning systems cover both imports and exports,[83] though only half of respondents noted that transshipments are also included in their radiation-detection program.[84] Implementing systems for scanning transshipments can be more challenging than for imports and exports, since there is less likely to be a "natural bottleneck" where detection equipment can be placed.[85] However, an absence of transshipment

[76] IAEA, "Nuclear Security Systems and Measures for the Detection of Nuclear and Other Radioactive Material out of Regulatory Control."
[77] Fifteen of twenty-four respondents had national guidance in place.
[78] Quoted from a single survey respondent.
[79] Four of twenty-four did not have national-level guidance, and five were unsure about it.
[80] Of thirteen respondents to this question, six reported that over 80 percent was scanned; four reported less than 20 percent; two reported 40–59 percent; one reported 60–79 percent.
[81] Note that seaports are selected for participation in the Megaports Initiative based on a number of factors including shipping volume but also threat factors, container export destimations, and proximity to facilities with special nuclear materials. See GAO, "Combating Nuclear Smuggling: Megaports Initiative Faces Funding and Sustainability Challenges," GAO-13-37, October 2012, p. 2.
[82] Phil Williams, "Transnational Criminal Networks," in John Arquilla and David Ronfeldt, eds., *Networks and Netwars* (Santa Monica, CA: RAND, 2001), p. 71.
[83] Twenty-four respondents claimed that their system scanned imports, and twenty-one suggested that exports were scanned.
[84] Fourteen respondents claimed that their system scanned transshipments.
[85] Paola Papa, "US and EU Strategies for Maritime Transport Security: A Comparative Perspective," *Transport Policy*, No. 28 (2013), p. 79.

scanning reduces the opportunities for intercepting undeclared nuclear or radiological materials, particularly if they are shipped between distant locations where a container might be offloaded multiple times during its journey.

Respondents were not asked to comment on the relative frequency of innocent versus non-innocent alarms, but it is clear from interviews and other studies that the vast majority of alarms are triggered by either NORM or legitimate shipments of radioactive materials.[86] A 2006 report by Lawrence Livermore National Laboratory, drawing on data from the Port Import/Export Reporting Service (PIERS), estimated shipments of NORM or legitimate radioactive materials made up approximately 4 percent of TEU imports into the United States.[87] A 2017 report by Oak Ridge National Laboratory, drawing on data from over thirty countries, calculated average alarming rates for RPMs at seaports at just over 1.5 percent.[88] Clearly NORM and other commercial radioactive materials make up a small but significant proportion of total cargo flows. This can result in a large number of alarms at busy maritime facilities which have to be assessed and investigated by FLOs on a daily basis.

The causes of non-innocent alarms identified by respondents were diverse and included contaminated goods, mislabeled sources, orphan sources, and special nuclear material.[89] The presence of the first three types of material in supply chains has been widely reported and clearly demonstrates the ability of detection systems to identify a broad range of radioactive materials. However, there is minimal information available on the frequency of fissile materials such as HEU or plutonium intercepted through radiation-detection systems employed for border-monitoring purposes.[90] Some studies have suggested that deployed systems are unlikely to detect these materials.[91] This makes the identification of special nuclear materials by survey respondents a significant finding. Although it was not possible to obtain further information on these cases, it implies that current systems are at least technically capable of detecting special nuclear materials.[92]

In this study, approximately one-third of respondents reported innocent alarm rates greater than 10 percent, while just under 15 percent put this at less than 1 percent.[93] This order-of-magnitude variation may be partially explained by differences in shipping routes for NORM. However, it likely also results from variation in alarming thresholds for RPMs.[94] At facilities where alarming thresholds are set relatively high, only particularly

86 Former public health official, personal interview with one of the authors, July 19, 2017.

87 M.-A. Descalle, D. Manatt, and D. Slaughter, "Analysis of Recent Manifests for Goods Imported through US Ports," Lawrence Livermore National Laboratory Report, UCRL-TR-225708, October 2006, <https://e-reports-ext.llnl.gov/pdf/339093.pdf>.

88 "Nuclear Smuggling Detection and Deterrence FY2016: Data Analysis Annual Report," Oak Ridge National Laboratory, January 2017, p.12.

89 Eleven respondents had found orphaned or disused sources; seventeen, contaminated goods; six, radiological sources mislabeled on the manifest; six, nuclear material; and six, special nuclear materials. One respondent also found "medical isotopes in waste."

90 One known example involving the detection of HEU by border-monitoring equipment occurred in Georgia in 2000. Please see GAO, "Nuclear Nonproliferation: US Efforts to Help Other Countries Combat Nuclear Smuggling Need Strengthened Coordination and Planning," GAO-02-426, May 2002, <www.gao.gov/assets/240/234392.pdf#page=36>, p. 33.

91 Gary M. Gaukler, Chenhua Li, Yu Ding, and Sunil S. Chirayath, "Detecting Nuclear Materials Smuggling: Performance Evaluation of Container Inspection Policies," *Risk Analysis*, November 1, 2011, p. 549

92 Given sensitivities around the interception of HEU and plutonium, it was not possible to obtain more information on how and in what quantities special nuclear material was detected.

93 Nine of twenty-one respondents placed innocent alarms at over 10 percent of cargo; three of twenty-one respondents placed innocent alarms at less than 1 percent of cargo.

94 Given sensitivities, respondents were not asked to identify alarming thresholds for RPMs.

radioactive shipments will trigger alarms, resulting in low alarming rates. This variation is arguably in part due to an absence of international guidance or standards for setting alarming thresholds, but, as is discussed below, commercial considerations are also a strong influence.

There was even greater variation in the assessment of and response to primary alarms. Approximately 10 percent of respondents stated that secondary inspections were undertaken in 10 to 50 percent of cases; for nearly one-quarter of respondents, this occurred between 1 and 10 percent of the time, just under 20 percent claiming that secondary inspections were conducted less than 1 percent of the time following an initial alarm.[95] This is despite the vast majority of respondents stating that they had access to more than one form of radiation detector, including handheld RIIDs for secondary inspections, with some facilities also employing X-ray systems.[96] The observed variation in secondary and tertiary inspections is surprising and implies that, for a significant number of facilities, NORM determination is made almost exclusively by FLOs assessing RPM radiation readings and profiles against the cargo manifest information.

In cases where the implemented scanning protocol uncovers undeclared radioactive materials, response will typically involve a number of domestic agencies, particularly customs, law enforcement, and nuclear and environmental regulators. Further, dependent upon national response plans, international bodies including the IAEA are often informed, as are transit states and, most often, the country of origin.[97] In terms of coordinating the response to MORC discovery, several respondents and interviewees indicated that these are largely ad hoc, "developed on a case-by-case basis."[98] The representative of an international shipping company emphasized that many states appeared to "reinvent the wheel" each time, underlining the lack of a standard response to detection events.[99]

Procedures at different ports and national authorities for dealing with material removed from the maritime supply chain can vary. Typically, materials are initially stored on site at the port, or at an off-site location, most respondents indicating that they eventually seek to return materials to their country of origin (though this is obviously unlikely in the event that threat materials were discovered). There are a number of challenges to this "return-to-sender" policy, including locating a carrier licensed (and willing) to carry radioactive materials.[100] There have also been cases where, for example, the manufacturer of radioactively contaminated goods has gone bankrupt, creating uncertainty as to where the materials should be returned and who should bear the cost.[101]

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95 Four of twenty-one respondents suggested that secondary inspections were undertaken in less than 1 percent of cases; five of twenty-one suggested 1–10 percent of cases; two of twenty-one suggested that they were undertaken in 11–50 percent of cases; three of twenty-one suggested they were undertaken in more than 90 percent of cases and seven of twenty-one responded to the question by selecting "unknown."

96 Twenty of twenty-three respondents suggested they had RPMs; eighteen of twenty-three had handheld detectors; and sevent of twenty-three had vehicle-based systems. Five of twenty-three respondents suggested they had access to all three types. Seth Van Liew, William Bertozzi, Nathan D'Olympia, Wilbur A. Franklin, Stephen E. Korbly, Robert J. Ledoux, and Cody M. Wilson, "Identification and Imaging of Special Nuclear Materials and Contraband Using Active X-ray Interrogation," *Physics Procedia*, Vol. 90 (2017), p. 314.

97 More importance was placed by respondents on informing national rather than international bodies.

98 Representative of global shipping company, personal interview with two of the authors, September 15, 2015.

99 Ibid.

100 Designated as International Maritime Dangerous Goods Code Class 7.

101 See, for instance, IAEA, "Strengthening Control over Radioactive Sources in Authorized Use and Regaining Control over Orphan Sources," IAEA-TECDOC-1388, <www-pub.iaea.org/MTCD/Publications/PDF/te_1388_web.pdf>, p. 10

Drivers: what dictates the implementation of radiation detection?

At the international level, the perceived threat of nuclear terrorism has driven the installation of nuclear- and radiological-detection systems at borders. A small number of states—most notably the United States—as well as international organizations such as the IAEA have promoted these efforts. Their impact is reflected in the survey results, half of all respondents suggesting that their national radiation-detection programs were initiated through some form of international partnership.[102]

Although border-monitoring systems may have been established through bilateral or international support programs, their precise implementation—as with any nuclear-security measure—rests with the individual state concerned. As discussed in the previous section, there is significant variation between states in the operation of detection systems in the maritime environment. To some extent, this reflects the different priorities of national detection programs: the majority of survey respondents noted that their systems aimed to detect all types of nuclear and radiological MORC, while one in five respondents revealed that theirs were concentrated primarily on identifying radioactive materials that posed a clear health and safety risk.[103] By contrast, the United Kingdom is known to operate a border-monitoring system based on a narrow counterterrorism rationale.[104]

It is unsurprising that safety concerns drive the operation of radiation-detection systems given the relatively high numbers of incidences involving inappropriately packaged radioactive goods, including those that are incorrectly recorded on the manifest as well as contaminated items. In the latter category, there have been hundreds of recorded cases where radioactive sources such as cobalt 60 were introduced into the smelting process for metals such as stainless steel before being transported to buyers around the world.[105] This contrasts with a limited number of instances involving the deliberate trafficking of nuclear or radiological material by potentially malicious actors. This may explain, for example, the observed lack of secondary inspections at certain facilities, as primary alarm assessment may be sufficient to identify the presence or absence of strongly radioactive cargo that poses a clear health risk. However, an approach that focuses primarily on detecting strongly radioactive materials is likely to be ineffective at identifying less-radioactive materials such as HEU.

Commercial drivers also influence the implementation of radiation-detection systems, both national authorities and system operators recognizing the need to minimize disruption to the flow of goods through the maritime supply chain. The provision of "better customer service," reduced "turnaround time," and increased "flow efficiency" are important factors in the selection of container-terminal selection by commercial entities and, hence, are critical for attracting high traffic volumes.[106] The importance of efficiency continues to

[102] Eighteen of thirty-six respondents indicated that international partnership had been involved in initiating their radiation detection programs.

[103] Sixteen of twenty-four respondents suggested that their system was to detect all MORC; five suggested that theirs focused on health and safety risks alone.

[104] B. Wilson and K. Van Haperen, *Soft Systems Thinking, Methodology and the Management of Change* (London, UK: Macmillan, 2015), p. 107.

[105] Renate Sefzig, Bejoy Saha, and Gisela Stoppa, "Co-60 contaminated stainless steels in Germany experiences and first steps," presentation delivered at the International Conference on Control and Management of Inadvertent Radioactive Material in Scrap Metal, Tarragona, Spain, February 23–27, 2009, pp. 87, 265–67, 323.

[106] Wenkai Li, Colin Jones, and Mark Goh, *Planning and Scheduling for Maritime Container Yards* (Heidelberg, Germany: Springer, 2015), pp. 15–16.

increase, making the "competitiveness of ports within logistics chains a much higher priority than it was before."[107]

These commercial factors clearly have the potential to create tension in the operation of radiation-detection systems given the time it takes to conduct secondary and, in particular, tertiary inspections. On this matter, just under half of survey respondents identified the need to meet a target alarm rate as their number one concern when determining alarming thresholds for RPMs.[108] Somewhat concerningly from a security perspective, only one-third of respondents stated that alarm thresholds were dictated by the radiative properties of the MORC that their systems sought to detect.[109]

Challenges: operational and global

As discussed earlier, identifying small quantities of radiological and nuclear material in the rapidly moving maritime environment presents a number of intrinsic challenges for the design and operation of detection systems. Arguably, chief among these is the initial assessment of alarms, particularly given the relative abundance of NORM and legitimate shipments of nuclear and radiological materials.[110] For programs aiming to detect all MORC, including low-gamma-activity materials such as HEU, alarm thresholds for RPMs must be set relatively low, which increases both the number of false and innocent alarms as well as the possibility of time-intensive secondary and tertiary inspections. This challenge is compounded by a relative lack of international guidance in this area, and some reluctance to publish or share thresholds among the practitioner community due to perceived security concerns.[111]

Although a significant proportion of respondents felt they were able to manage innocent alarm rates, the effectiveness of protocols in identifying the deliberate trafficking in certain scenarios is unclear.[112] For example, detecting small quantities of nuclear material purposefully concealed within NORM shipments or deliberately shielded could prove problematic or unlikely, given a relative absence of secondary and tertiary inspections at certain facilities. Related to this, for a small but noteworthy fraction of respondents, the most pressing challenge in implementing detection systems was the ability of FLOs to stop and detain alarming containers so that secondary and tertiary inspections could be performed.[113] Human-resource constraints drive this issue, especially at ports with high alarm rates, as does pressure to avoid significant disruption to cargo flows.

A high proportion of survey respondents also highlighted resource issues including equipment, operating, and sustainability costs as key challenges to implementing

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107 Cimen Karatas-Cetin, "Port and Logistic Chains: Changes in Organizational Effectiveness," in Dong-Wook Song, Photis Panayides, eds., *Maritime Logistics*, 2nd edn, (London, UK: Kogan Page, 2015), pp. 343–72.

108 Twelve of twenty-five respondents noted that target alarm rate was the most important factor in determining alarm thresholds.

109 Only eight of twenty-five indicated that it was based on the material that the system was seeking to detect.

110 Radiation-detection expert at international organization, personal interview with one of the authors, July 12, 2018.

111 Comments by several survey respondents.

112 Seventeen of twenty-one respondents felt their organization was able to manage the number of innocent alarms produced by NORM.

113 Four of twenty-three respondents noted that detaining containers in order to carry out secondary and tertiary inspections was the greatest challenge they faced.

radiation-detection systems.[114] At some facilities, for example, a lack of operational handheld RIIDs directly limits their use in secondary inspections.[115] FLO training was also found to vary significantly: most respondents reported undergoing training annually or less, while two respondents noted that they had never been offered training.[116]

Sustaining bilateral and multilateral efforts that promote radiation-detection systems can be challenging. A 2012 US Government Accountability Office report on the Megaports Initiative noted a myriad of related issues including: the limited use of secondary scanning equipment, counter to training provided by US trainers; a lack of or partial buy-in amongst stakeholders; and criticism of sustainability plans.[117] High-level political developments, such as program funding cuts, and deteriorating diplomatic relations with international partners also present challenges in this area that are difficult to mitigate.[118]

Improving detection: information sharing, promoting best practice, and new tools

Given that radiation-detection systems at maritime facilities worldwide have now been implemented for many years (in many cases, upward of a decade), there exists a mature pool of experts comprising a diverse international community of practitioners. However, lessons learned are not always effectively disseminated throughout the border-monitoring community; the overwhelming majority of survey respondents felt that enhanced information sharing with professionals in other countries could help improve the system operation in their own state. Relatedly, respondents were clear that additional guidance from international organizations would be beneficial.[119] This is surprising, given that there already exist a number of IAEA documents relevant to the operation of radiation-detection systems, including one Implementing Guide and two detailed Technical Guides.[120] This response may reflect the fact that some of these documents are more than ten years old and, consequently, should be updated to take account of more recent developments. Alternatively, a lack of openness and sharing of best practice within practitioner communities due to security concerns may be an issue. For instance, the IAEA guidance document Technical and Functional Specifications for Border Monitoring Equipment has a restricted distribution and can only be requested by a state's

114 Eight respondents of twenty-three selected sustainability costs as the greatest challenge; fourteen respondents selected cost-related issues as the greatest challenge (sustainability costs, inspection costs, staffing shortages, and equipment malfunction).

115 Radiation-detection expert at international organization, personal interview with one of the authors, July 12, 2018.

116 Seven observe training once a year, five observe training two to three times a year, two had never been trained, three were trained less than once a year, and two reported training for only new officers.

117 GAO, "Combating Nuclear Smuggling: Megaports Initiative Faces Funding and Sustainability Challenges," GAO-13-37, October 2012, pp. 28–35.

118 For example, 85 percent of Megaports program funding was cut in 2012. "Obama Slashes Funding for Megaports Program," Nuclear Threat Initiative, December 11, 2012; Russia, accounting for 45 percent of the US Second Line of Defense program's sites, halted much cooperation in the area of nuclear security in 2014. See GAO, "Combatting Nuclear Smuggling: NNSA's Detection and Deterrence Program Is Addressing Challenges but Should Improve Its Program Plan," p. 3.

119 Sixteen out of twenty-one respondents supported the development of new technical international scanning guidelines or requirements.

120 IAEA, "Technical and Functional Specifications for Border Monitoring Equipment," Nuclear Security Series No. 1, 2006; IAEA, "Nuclear Security Recommendations on Nuclear and Other Radioactive Material out of Regulatory Control," Nuclear Security Series No. 2, 2011; IAEA, "Combating Illicit Trafficking in Nuclear and Other Radioactive Material," Nuclear Security Series No. 6, 2007; IAEA, "Nuclear Security Systems and Measures for the Detection of Nuclear and Other Radioactive Material out of Regulatory Control," Nuclear Security Series No. 21, 2013.

relevant mission to the IAEA or nuclear regulatory body.[121] Over half of respondents also suggested that the operation of detection systems could be improved by publishing information on alarming limits for NORM shipments.[122]

As mentioned above, there is a perennial tension between the release of information on nuclear-security measures to improve detection systems and the risk that adversaries will use that information to identify and exploit weaknesses. This balance has long been biased toward the protectionist end of this spectrum, although there has been a considerable shift in favor of greater disclosure in recent years.[123] On the issue of maritime MORC detection in particular, states could engage one another to a much greater extent than they currently do, sharing information about the challenges encountered and how they have been overcome. There are several international fora within which information exchange can occur, notably the IAEA's Border Monitoring Working Group. Further, project-based opportunities including the IAEA Coordinated Research Project format enable states to work together to advance mutual understanding of these issues.[124] However, involvement in these initiatives is currently limited to a small fraction of states that deploy border-monitoring systems and typically requires the investment of both time and financial resources.[125]

With regard to additional guidance, there is scope to update relevant IAEA documents drawing on practitioner experience gleaned over the past decade. There is also scope for a new publication either focused on radiation detection at maritime facilities in particular or dealing with pressing challenges in the maritime environment.[126] For example, innocent alarms rates tend to be higher at seaports than at airports and land crossings, due to the shipment of significant quantities of mildly radioactive bulk commodities in this environment.[127] As a consequence, tailored guidance on how to manage these high rates in a busy operational environment could be beneficial. In developing new guidance, however, there will be limits to the specificity of publishable information: despite the clear benefits to openly sharing information on how to determine alarm thresholds, persistent state-level security concerns are unlikely to change in the immediate future.

Instead of sharing sensitive operational information to help other states more efficiently identify alarms, states could consider developing and sharing new alarm assessment tools. Efforts are already underway in this area, most notably the development of a new IAEA Tool for Radiation Alarm and Commodity Evaluation (TRACE), which is being made available as a mobile application for use by FLOs.[128] This tool provides information on the specific radioisotopes contained within common commodities.[129]

[121] <www-pub.iaea.org/books/IAEABooks/7400/Technical-and-Functional-Specifications-for-Border-Monitoring-Equipment##description>.
[122] Suggested by eleven of twenty-one respondents.
[123] Wyn Q. Bowen and Christopher Hobbs, "Sensitive Nuclear Information: Challenges and Options for Control," *Strategic Analysis*, Vol. 38, No. 2 (2014), pp. 225–26.
[124] IAEA, "Improved Assessment of Initial Alarms from Radiation Detection Instruments," CRP-J02005, and "Advancing Radiation Detection Equipment for Detecting Nuclear and Other Radioactive out of Material out of Regulatory Control," CRP-J02012, <http://cra.iaea.org/cra/explore-crps/all-active-by-programme.html>.
[125] Ibid.
[126] Note there currently exists a technical document for "Monitoring for Radioactive Material in International Mail Transported by Public Postal Operators" (NSS No. 3).
[127] "Nuclear Smuggling Detection and Deterrence FY2016: Data Analysis Annual Report," Oak Ridge National Laboratory, January 2017, p. 12.
[128] IAEA, "IAEA Launches Mobile Application Tool for Radiation Alarm and Commodity Evaluation," June 9, 2017, <www.iaea.org/newscenter/news/iaea-launches-mobile-application-tool-for-radiation-alarm-and-commodity-evaluation>.
[129] "IAEA's Mobile App Helps Sri Lanka to Fight Smuggling of Radioactive Materials," *Nuclear Asia*, June 13, 2018, <www.nuclearasia.com/gallery/iaeas-mobile-app-helps-sri-lanka-fight-smuggling-radioactive-materials/2331/>.

Looking ahead, there are increasing opportunities in the application of data-science techniques to the huge volumes of data generated by RPM operators and their international partners.[130] These applications are already used to support resource planning and to extract broader commercial trends. However, data mining could uncover new means of identifying subtle alarming anomalies that may be difficult for a human operator to assess.[131]

Given the diverse rationales underpinning states' detection systems—ranging from public health and safety to nuclear and radiological counterterrorism—renewed efforts should focus on developing an ongoing international nuclear-security dialogue similar to that generated and sustained through the NSS process. This is a challenging task due to states' varying threat perceptions and sensitivities around certain parts of the detection process, such as alarm thresholds. But real-life case studies and tabletop exercises are one way to ensure that those operating radiation-detection equipment are aware of the credible threat to nuclear and radiological materials, while facilitating discussion of what this means for detection systems and alarm levels.

Though it is difficult to completely mitigate the impact of political developments on radiation-detection programs, there are a number of ways to sustain their operation. Organizations investing in equipment and human resources for radiation detection at the national level and in support of international partners should incorporate plans to ensure the longer-term sustainability of their investments. The United States and others working to spread these capabilities should also ensure that engagement plans emphasize sustainability aspects, factoring in appropriate time and resources to transition away from international support. Requesting partners to invest in these capabilities alongside US financial assistance can also provide a sense of ownership, which is beneficial in the long term.[132]

Conclusion

It is clearly challenging to effectively deploy radiation-detection systems in maritime border-monitoring efforts. Although many systems are developed through bilateral and international partnerships, their effectiveness diverges significantly in various facilities. At some maritime facilities, security concerns drive a system's operation, while for others, safety and commercial factors take precedence. The result is a diverse set of approaches to crucial aspects of the detection process including the assessment of—and response to—alarms generated by cargo passing through RPMs.

Arguably, the fragmented approaches observed throughout the maritime supply chain reduce the effectiveness of the global nuclear-detection architecture in stymying the illicit trafficking of nuclear and radiological materials. In order to bring greater coordination to a system characterized by considerable divergence, states and international organizations promoting border monitoring should make serious efforts to renew the waning

130 "Nuclear Smuggling Detection and Deterrence FY2016: Data Analysis Annual Report," Oak Ridge National Laboratory, January 2017, pp. 8, 26.

131 There is a host of data-science techniques such as dynamic time warping, random forest, and neural networks that could potentially be applied to RPM data in support of the alarm assessment process.

132 GAO, "Combatting Nuclear Smuggling: NNSA's Detection and Deterrence Program is Addressing Challenges but Should Improve Its Program Plan," GAO-16-460, June 2016, p. 17.

international nuclear-security dialogue, with a particular focus on the importance of combating illicit trafficking. This discourse should be supported by developing and publishing new and updated international guidance documents, exchanging operational best practices, and developing new tools in support of FLOs. These steps could mitigate some of the practical challenges encountered in alarm assessment, to better identify threat materials in the ever-expanding maritime supply chain.

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Appendix. Summary of survey questions and responses

In its discussion of how and why radiation-detection systems are implemented, this article draws on data obtained through surveying practitioners involved in their development and operation at maritime facilities. An online tool was used to distribute the survey in September and October 2015 to an international border-monitoring community of practice. The survey contained a total of thirty-one questions relating to the implementation of detection systems at maritime facilities. Given both potential perceived sensitivities around some of the questions and possible lack of relevance, participants were able to skip questions should they so choose. Comment boxes were also included for each question; here, participants could provide additional information to further clarify their response. These were utilized by a significant number of participants; several of their comments were referred to in this article.

Before taking the survey, participants were first asked to identify the type of organization at which they were employed and the region within which they worked. Respondents were also able to optionally specify the country in which they worked. A total of thirty-six responses were received from individuals from every region of the world. Respondents included government officials, radiological and environmental regulators, border security and customs officials, port authorities, shipping companies, and other private entities that interact with border-monitoring systems. Respondents either chose not to or were unable to answer every survey question due to the range of issues covered, their different roles and responsibilities, and perceived sensitivities associated with certain questions. This resulted in a drop-off in responses to certain questions, some having less than twenty respondents. However, this is not seen as a significant issue for this study, as its primary purpose is not to provide a precise statistical analysis of the operation of radiation-detection systems in the maritime environment. Rather it seeks to illustrate the wide variation in how and why such systems are being implemented and to solicit suggestions for how this could be improved.

Provided below are the specific survey questions and associated responses that were drawn upon in this article and can be found referenced within the text.

Was this detection program mandated or initiated by the following (include all that apply)?	
Total responses	36
Government mandate	16
International partnership	18
Private commercial initiative	3
International commitment	6
Other	2

Have national guidelines been developed for the uniform application of detection systems at ports throughout your country or the countries in which you operate?	
Total responses	24
Yes	15
No	4
Unknown	5

What types of material are you or your organization attempting to detect and remove from the maritime supply chain?	
Total responses	24
All materials outside regulatory control (MORC)	16
Only materials that involve criminal intent or threat	1
Only materials that pose a health and safety risk (for example, contaminated materials or disused sources)	5
Other	2

Which of the following would you consider your HIGHEST priority when determining the alarm threshold settings for your radiation detection systems across all MORC?	
Total responses	25
The type of material(s) you are attempting to detect	8
The alarm rate (i.e. alarm threshold set to achieve a target alarm rate or to reduce the number of “innocent/nuisance” alarms)	12
Unknown	4
Other	1

What types of radiation detectors are routinely used for scanning at your ports (include all that apply)?	
Total responses	23
Fixed radiation portal monitors (RPMs)	20
Vehicle-based systems	7
Handheld/portable systems	18
RPMs and handheld devices	9
Vehicle-based handheld	2
All three of the above (RPM, vehicle-based, and handheld)	5
Other (box)	

Which of the following traffic types are included in your radiation-detection programme (include all that apply)?	
Total responses	25
Imports	24
Exports	21
Transshipments	14
Unknown	0

If applicable, estimate the annual proportion of import, export, and transshipment containers throughout scanned with radiation-detection equipment for the ports in which you operate.

	Imports	Exports	Transshipments
Total responses	13	11	10
0–19%	4	6	6
20–39%	0	1	0
40–59%	2	0	3
60–79%	1	0	0
80–100%	6	5	1

What is the greatest challenge you or your organization faces in operating radiation-detection systems?	
Total responses	23
Equipment malfunction or failure	2
Staffing shortages	2
Ability to stop or detain containers	4
Ability to return or dispose of material	3
Equipment, operating, or sustainability costs	8
Costs associated with moving or inspecting containers	2
No major challenges	0
Other	2

What types of nuclear or radiological material has your detection system identified (include all that apply)?	
Total responses	19
Orphaned or disused sources	11
Contaminated goods	17
Radiological sources labelled incorrectly on manifest	6
Special nuclear material	6
Other nuclear material (for example, low enriched uranium, natural uranium, depleted uranium or thorium)	6
Other	1

How often does your radiation-detection system trigger alarms in which radiation is present but the source is naturally occurring radioactive material (NORM) as a proportion of total containers scanned?	
Total responses	21
Less than 1%	3
1–2%	0
3–5%	1
6–10%	3
More than 10%	9
Unknown	5

Are you or your organization able to manage the number of alarms in which radiation is present but the source is NORM?	
Total responses	21
Yes	17
No	1
Unknown	3

How frequently are radiation portal monitor (RPM) alarms investigated with a handheld radiation detector to identify the alarming isotope?	
Total responses	21
Less than 1%	4
1–10%	5
11–50%	2
51–90%	0
More than 90%	3
Unknown	7

How often do you or your organization provide training or education on the use of radiation detection systems or technologies to front-line operators?	
Total responses	21
Never	2
Less than once per year	3
Once per year	7
Two or three times per year	5
More than three times per year	0
Only for new officers	2
Unknown	2

How might scanning for nuclear and radiological materials outside regulatory control be improved within your country or the countries in which you operate (include all that apply)?	
Total responses	21
International scanning guidelines or requirements	16
Information sharing with other countries	17
Published NORM limits (accept/reject cargo) by other countries	11
Government-to-government notification for MORC that is returned to origin	9
Technical improvements to assist operators in identifying alarms in which radiation is present but the source is NORM	8
Scanning at additional ports	8
Legal requirement for scanning	5
Scanning a greater proportion of container traffic	4
Conduct further investigation of a greater proportion of containers that trigger an alarm	3
Encourage more inter-agency coordination (for example, emergency response, source recovery, nuclear forensics)	10
No significant improvements necessary	0
Other	1